Verification and Validation of the Eagle Combat Model's Attrition Processes

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VERIFICATION AND VALIDATION OF THE EAGLE COMBAT MODEL'S ATTRITION PROCESSES

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The major attrition processes (direct-fire, artillery, on-station helicopter, system-on-system acquisition) in the Eagle combat model had never had an independent verification and validation (V&V) of the relevant code. Using Army Pam 5-11 accepted V&V methods, Eagle code was verified and validated to the Vector-In-Commander (VIC) model.

All these functional areas were verified. Some problems were found but corrected. With the code changes made and exceptions noted in the body of this report, Eagle's code does function as intended.

System-on-system acquisition; direct-fire, and on-station helicopter attrition validate to the most up-to-date VIC (versions 5 and 6). Eagle's artillery attrition validates to VIC version 3.0. It needs to be updated to the latest Artillery School and AMSAA approved artillery algorithms.

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ABSTRACT

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VERIFICATION AND VALIDATION

OF THE EAGLE COMBAT MODEL'S ATTRITION PROCESSES

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1. Introduction.

a. *Background.*

(1) The major attrition processes in the Eagle combat model have never had an independent verification and validation (V&V) of the relevant code. Direct-fire attrition, indirect-fire (artillery) attrition, on-station helicopter attrition, and the acquisition used for both direct-fire and on-station helicopter firing engagements were examined in this V&V effort.

(2) Per the Department of the Army Pamphlet 5-11, "Verification, Validation, and Accreditation of Army Models and Simulations," dated 15 October 1993: "Verification is the process that determines that the M&S [models and simulations] functions as it was originally conceived, specified and designed." Verification does not address the applicability of the portrayal of the real-world processes attempted to be simulated. Verification is the checking of the logical algorithms and software written to ensure that the resulting computer code is what the original programmer had intended. Verification methods can be divided into three groups: logical, code, and those methods applicable to both. Logical verification methods, as specified in Army Pamphlet 5-11, are: documentation review, design walk-throughs, and comparisons of both specifications to requirements and design to specifications. Applicable code verification techniques include: sensitivity analyses and stress tests, code walk-throughs, automatic test-tools, mathematical stability across platforms, and checking for consistency of units of measurement used. Algorithm checks can be done for both logical and code verification.

(3) "Validation is the process that addresses the creditability of the M&S [models and simulations] in its depiction of the modeled world." Eagle's attrition processes are to be validated by comparing their output to that of those of the corresponding Vector-in-Commander (VIC) model processes. The technical methods for validation are: face validation (are the results feasible?), comparison to other accredited M&S, functional decomposition, and stress tests with sensitivity analyses.

b. *General verification process.*

(1) It was discovered early in the review of the Eagle combat model's requirements and specifications that the attrition processes under analysis in this report coincided with those found in the VIC combat simulation *as it was configured when Eagle was begun.* That was VIC version 3.0, developed in 1987. VIC has undergone many modifications/improvements since 1987 and version 6.0 has been completed though not yet released by the TRADOC Analysis Center, Operations Analysis Center (TRAC-OAC), Modeling and Research Directorate (MRD). Later versions of VIC would not be suitable for V&V purposes with Eagle because of the magnitude of these changes.

(2) The Combined Arms Map Exercise (CAMEX) model also developed by TRAC-OAC, MRD, was thought to use VIC version 3.0 code for all the functional areas of interest for this study (the artillery methodology was discovered to be from 1988-1990 VIC version 4.0; this will be discussed in more detail in that section of this report). Therefore, CAMEX code (VIC version 4.0) and VIC version 3.0 documentation were used for this V&V effort. For simplicity, the common code found in both CAMEX and VIC will be called VIC, without a version number unless relevant to the discussion.

2. Acquisition for both direct-fire and on-station helicopter attrition--verification and validation.

a. Both Eagle and VIC use the CECOM Center for Night Vision and Electro-Optics (C2NVEO) Search model (a.k.a., Night Vision Lab Search Model (NVL Search Model) and CNVEO Search Model) to develop the acquisition inputs needed for both direct-fire and on-station attrition processes. Acquisition rates (acq-rates) for each firer versus each target system are the only acquisition parameters needed by these attrition methodologies. The rates are derived from the Search model outputs (probability of ever-acquiring (P_∞ and P-infinity), and the expected time to acquire ($\bar{t}$ and t-bar) from versions of the search model run by TRAC, Simulation and Data Standards Directorate (SDSD), Data Development Division (DDD).

acq-rate = 1 / [(search-sector/field-of-view) * t-bar]

where:

- [(search-sector/field-of-view) * t-bar], the denominator in the above equation, is the expected time to acquire a target given that it is located within the search sector of the firer.

- search-sector (field-of-regard) is the horizontal sector of search assigned to the firer. It is a gamer input (commander's decision) and is measured in degrees.

- field-of-view is the horizontal sector of viewing in degrees of the sensor being used by the firer. This is reflective of the mode of the sensor (low magnification/wide field-of-view; or high magnification/narrow field-of-view) being used and is an engineering characteristic of the sensor being used.

- t-bar is the expected time to acquire a target, given it is located within the sensor's field-of-view. [1 / t-bar] is the acquisition rate for this sensor, given a target is within its field-of-view.

- P-infinity and t-bar are developed as functions of: the sensor and its mode of use, the acquisition task being performed, target posture (stationary or moving), target exposure (fully-exposed or hull-defilade, fully-exposed or mast-only exposed for helicopter targets), scenario environmental conditions, firer posture (stationary or moving), and firer- target range.

b. The acquisition rate derivation routines in Eagle and VIC have been both *verified* (the code of each yields the same algorithm) and *validated* (they do produce the same output given the same input). The DDD versions of the C2NVEO search model used to develop the raw inputs needed for Eagle and VIC were extensively verified and validated to ensure the algorithms used, the underlying assumptions made, and the output produced were the same (circa 1989). DDD has made validation runs on the two versions of the search model when any changes have been made to either model (usually just output format changes) and they still validate.

c. Both VIC and Eagle need to have their acquisition rate derivation code modified to never allow the fraction [search-sector / field-of-view] to have a value of less than one. If this is allowed to happen, the resulting acquisition rates would be better than [1 / t-bar] - the highest acquisition rate possible for this sensor-target combination given the circumstances.

3. Direct-fire attrition and on-station helicopter attrition.

a. *Background*. Both Eagle and VIC use Lanchester Square Law based attrition algorithms for resolving direct-fire battle and on-station helicopter results which, in general, mean:

$$\text{Kills of Blue Forces} = \text{Attrition Coefficient} * \text{Number of Red Firers} * \text{Time}$$

and, similarly, for kills of Red forces. The calculation of these attrition coefficients comes from the Vector model methodology developed by Seth Bonder and Robert Farrell of Vector Research, Incorporated (VRI), and is commonly called the

"Bonder-Farrell methodology." For a complete explanation of the Bonder-Farrell methodology, refer to any of the VRI or VIC attrition coefficient calculation documents listed in the bibliography.

b. *Verification.*

(1) Specific methods used to verify the direct-fire and rotary wing on-station attrition processes were:

- review of VIC version 3.0 documentation,
- review of many Bonder and Farrell documents,
- review of Eagle software requirements documentation,
- code walk-throughs of Eagle,
- code walk-throughs of VIC 3.0 code,
- comparisons of the above five items' methodologies,
- units consistency checks for Eagle, and
- sensitivity analyses and stress tests of Eagle direct-fire and on-station helicopter methods and code.

(2) The specific problems uncovered as a result of the verification were:

(a) The discovery and correction of coding mistakes in the calculation of the probability of detection of a target-type for the particular combat situation. A "cut and paste" mistake where the second term of the expected time to detect was accidentally an addend in the calculation of the probability of detection. In the Eagle routine bonder-farrell-methods.lisp within the method get-df-serial-term-vars, the code was:

```
(setq
fl-prob-of-selecting-target (+ 2nd-term-of-time-to-select-target)
                              (*term fl-acq-rate-x-prob-los-x-nr-tgts))
```

and was changed to:

```
(setq
fl-prob-of-selecting-target  (+ 2nd-term-prob-selecting-target
                                (* term fl-acq-rate-x-prob-los-x-nr-tgts)))
```

(b) Also due to the incorrect order of parentheses and functions in the Eagle code, a factor that was supposed to be an exponent in the calculation of the probability of detection was implemented as a multiplier. The code found in the same method had been written as:

```
(cond ((> target-priority-in-list 2)
        (setq srntt (+ (* (EAGLE-exp (- tgt-1-target-search-cutoff-time))
                          tgt-1-fl-sum-acq-rate-x-prob-los-x-nr-tgts)
                          tgt-2-fl-sum-search-time-x-acq-rate-x-plos-x-nr-tgts)))

        (setq srntt (* (EAGLE-exp (- tgt-1-target-search-cutoff-time))
                          tgt-1-fl-sum-acq-rate-x-prob-los-x-nr-tgts)))
```

but was rewritten to:

```
(cond ((> target-priority-in-list 2) ;; changed to match VIC - DRL, 15APR94
        (setq srntt (EAGLE-exp (+ (- (* tgt-1-target-search-cutoff-time
                          tgt-1-fl-sum-acq-rate-x-prob-los-x-nr-tgts))
                          tgt-2-fl-sum-search-time-x-acq-rate-x-plos-x-nr-tgts))))

        (setq srntt (EAGLE-exp (- (* tgt-1-target-search-cutoff-time
                          tgt-1-fl-sum-acq-rate-x-prob-los-x-nr-tgts)))))
```

With these changes, the implementations of the Bonder-Farrell methodology in Eagle and VIC now match.

(c) Checking for consistency among the units of measurement used in the Eagle direct-fire methods uncovered problems--some rates were calculated per minute when the methods that used them expected per second values. In the Eagle routine bonder-farrell-methods.lisp within the method U-calculate-firing-rate, the code had been written to calculate the firing rate as:

```
(* 60 total-fraction-time-firing rof)
```

but was changed to:

```
(* total-fraction-time-firing rof)
```

In the Eagle routine sys-mun-methods.lisp within the P-basic-vis-acq-rates method, the acquisition rates for a firer were multiplied by 60 and returned as a per minute value:

```
(cond ((null rates) (list 0.0 0.0 0.0 0.0))   ;;convert from seconds to minute
      (t (list (* 60.0 (first rates)))   ;;target moving -fully exposed
               (* 60.0 (second rates))   ;;target moving -hull defilade
               (* 60.0 (third rates))    ;;target stat -fully exposed
               (* 60.0 (fourth rates))) ))   ;;target stat -hull defilade
```

but these "* 60"-factors were removed:

```
(cond ((null rates) (list 0.0 0.0 0.0 0.0))   ;;keep rates in seconds
      (t (list (* 1.0 (first rates))   ;;target moving -fully exposed
               (* 1.0 (second rates))   ;;target moving -hull defilade
               (* 1.0 (third rates))   ;;target stat -fully exposed
               (* 1.0 (fourth rates))) ))   ;;target stat -hull defilade
```

When these corrections were made, all rates and time units were expressed in seconds and used as per second values. There is now consistency of all units used within the Eagle direct-fire and helicopter attrition methods.

(d) The kill rate due to other firers [called $\bar{A}$ in the Bonder-Farrell documentation, and (/previous-loss-rate-tgt-group tgt-group-strength) in the method accumulate-serial-acq-rate-terms in the Eagle routine bonder-farrell-methods. LISP] is assumed to be zero in Eagle. These kill rates due to other firers are calculated in VIC. This is a definite difference between VIC's and Eagle's implementation of the Bonder-Farrell methodology. Code would have to be written for the Eagle model to calculate these others' kill rates. In all validation work done for this report, VIC's kill rate due to other firers was set to zero.

(e) A new firing rate method needs to be implemented and tested for Eagle. Ms. Moody, MRD, has written prototype code but it has never been incorporated into the model. Presently, the Eagle method U-calculate-firing-rate in bonder-farrell-methods.lisp consists of demo code (it returns an assumed "hardwired" rate-of-fire, (rof), for all firers). This firing rate does <u>not</u> affect the losses calculated using the Bonder-Farrel methodology but is only used to calculate ammunition consumed for logistics purposes.

(f) The ways direct-fire attrition data inputs are input and manipulated differ. In VIC, attrition data is loaded and calculated by firing weapon while Eagle is based on firing system. A firing system in VIC can "shoot" multiple weapon systems (gun, missile, machine-gun); while in Eagle, the firing system has only one set of attrition data that reflects the "best" weapon system to fire for each particular target/ battle situation (firer posture, target posture, range). Also, kill rates in VIC are interpolated for the range of a particular firer-target engagement, but Eagle uses a step- function approach to obtain kill rates (it uses the kill rate when a particular firer-target engagement's range is less than or equal to the range of a kill rates input). These differences will affect battle results; therefore, code needs to be written to give Eagle the same capabilities as VIC, if this is deemed necessary.

c. *Validation.*

(1) Both VIC and Eagle code produce the same attrition coefficients (the same to the hundred thousandths place, i.e., .000001) when given the exact same combat situation. This is true for the calculation of the attrition coefficients when both serial and parallel acquisition modes are used. The ranges of input values tested were:

(a) Acquisition type: parallel, serial;

(b) Number of target systems: 1 - 10;

(c) Quantity of each target system: 0 - 30.0;

(d) Probability of line-of-sight to each target system: 0.0 - 1.0;

(e) Invisibility rate (rate that targets that are in view drive out of the view of the firer): 0.0 - 1.0;

(f) Acquisition rate (rate that the firer acquires a target system given it is in sight and can ever be acquired, a.k.a., the reciprocal of the expected time to acquire such a target): 0.0 - 1.0;

(g) Probability of ever acquiring a target (P_∞): 0.0 - 1.0;

(h) Order of target systems on the target priority list;

(i) Target search cut-off times for serial acquisition: 0.1 - 999.0.

The two models produced the same attrition coefficients for all situations tested, except when the circumstances noted below occur.

(2) It was determined to be very difficult and time consuming (maybe impossible) to get VIC and Eagle to place units in exactly the same place, at the same time, and in the same condition to resolve a direct-fire combat situation. It was beyond the time and manpower constraints of this analysis to get exactly the same scenario into the two models' data bases and to get all (any) units and their actions to be executed at the same time. Rather than develop a set of matching data bases for VIC and Eagle that might possibly result in exactly the same combat situations occurring, the values needed to derive the attrition coefficients were input interactively in special variants of VIC and Eagle. This approach proved to be successful and allowed the comparison of the Bonder-Farrell methodologies' intermediate values and final

outputs. The resolution of direct-fire and on-station helicopter combat in Eagle does validate to that found in VIC.

(3) The small difference in the "same" attrition coefficients calculated in the two models result from the inherent dissimilarities in the numerical representation processes found in the two models' languages (VIC - Simscript, Eagle - Common LISP). This difference would account for less than a one kill change per 24 hours of constant direct-fire combat per firer.

(4) The only circumstances encountered that the particular implementations of the Bonder-Farrell methodology in VIC and Eagle may produce different attrition coefficients are:

(a) When the number of acquired target systems is greater than 20 for a firing weapon using the parallel acquisition firing discipline. In Eagle, whenever the number of acquired target systems is greater than 20, it is reset to 20 to prevent a larger exponent from causing the acquisition algorithm to "blowup".

(b) When the number of targets in range is very small (< 0.01). Eagle has no minimum nor maximum thresholds to attempt the calculation of attrition coefficients. VIC will only calculate an attrition coefficient whenever NR.TGTS.IN. RANGE > 0.01 for a particular target system. This number of targets in range is equal to the product of the number of systems in the target unit, the fraction of these systems active in the unit's quadrant involved in the attack, the phased engagement fraction, the fraction unsuppressed and unhidden, and the fraction of the target systems within the field-of-regard of the shooter.

(c) VIC will not proceed with serial acquisition attrition coefficient calculations whenever the probability of detecting all higher priority targets goes above .9998.

(d) These 3 circumstances happened only 13 times in the over 160 million potential firer-target pairings that occurred in an eight-hour Southwest Asia (SWA) scenario battle and produced no noticeable difference (surviving systems and those killed were the same to the hundredths place, i.e., .01).

4. Indirect-fire attrition.

a. *Verification.*

(1) Specific methods used to verify Eagle's indirect-fire attrition process were:

(a) Review of VIC version 3.0 documentation,

(b) Review of Eagle software requirements documentation,

(c) Code walk-throughs of Eagle,

(d) Code walk-throughs of VIC version 3.0,

(e) Code walk-throughs of the CAMEX,

(f) Comparisons of the above five methodology sources,

(g) Units consistency checks for Eagle,

(h) Sensitivity analyses and stress tests of the Eagle code.

(2) Eagle and VIC version 3.0 use the Super Quickie 2 and the Smart Munition Analysis in Reduced Time (SMART) indirect-fire attrition methodologies. These were the Army Materiel Systems Analysis Agency's (AMSAA's) standard artillery methodologies in 1987. Today's VIC (versions 5 and 6) uses the present AMSAA- and Field Artillery School-approved set of artillery algorithms, commonly known as ARTQUIK and improved SMART.

(3) Eagle and VIC version 3.0 implementations of the Super Quickie 2 and SMART methodologies are basically the same. All units of measure used in the Eagle artillery methods were consistent. The Eagle code functioned properly (as the VIC version 3.0 algorithms were written) when stress tests and sensitivity analysis runs were made. The only exceptions are:

(a) That Eagle makes the assumption that all targets (both real and false) will be detected and receive an equal quantity of submunitions in its fire-and-forget "smart" munition methodology.

(b) Eagle assumes that a unit has no subunits for indirect-fire targeting or assessment purposes.

(4) *It was discovered during the validation process that CAMEX no longer uses these VIC version 3.0 artillery attrition processes.* CAMEX has updated versions of Super Quickie 2 and SMART that resulted from the artillery peelback efforts in the 1988-1990 timeframe. CAMEX uses an updated Super Quickie 2 methodology for both improved conventional munitions (ICM) and high explosive (HE) munitions that was developed by AMSAA and implemented into version 4.0 of VIC. The algorithms used for smart (a.k.a., "fire and forget") munitions in CAMEX were also updated in a similar manner and in the same timeframe. These changes corrected deficiencies found in the VIC version 3.0 artillery routines during the artillery peelback. Now, Eagle contains the VIC version 3.0 artillery methodologies while CAMEX is VIC version 4.0.

(5) The differences between the Eagle (VIC version 3.0) and the present CAMEX artillery (VIC version 4.0) codes are:

(a) All variable names have been changed. VIC 3.0 has algebraic variables while VIC 4.0 has meaningfully-named variables. Although this should not make any difference in how the two models function, it does make code walk-throughs and comparisons quite difficult. No verification of the CAMEX (VIC version 4.0) artillery routines was made; this was deemed beyond the scope of the report and also unnecessary since this code needs to be replaced.

(b) Attrition assessment for both fire-and-forget and conventional munitions. Eagle assesses indirect-fire attrition versus units with uniformly distributed target systems. These target units are company sized for observed fire, but battalion sized for all other firings. No collateral damage to untargeted units in the area of the artillery fire is assessed. In CAMEX, subunits with templated positioning of target systems are assessed as artillery targets and untargeted units (subunits) can receive collateral damage.

(c) Fire-and-forget munitions calculations. Kills are determined by how many submunitions actually hit each target system. In Eagle, this number of submunitions per target system is calculated using the numbers of target systems found in each submunition's footprint and the number of submunitions found in the entire pattern. The new methodology in CAMEX bases the number of submunitions per target system on algorithms that use the fractions of subunit covered by each submunition's footprint and the entire pattern.

(d) Aiming strategy algorithms changed. Eagle uses an aiming strategy to optimally space volley aimpoints over a rectangular pattern target area for Blue firers (the battery computer system (BCS) aiming strategy). CAMEX employs an initial aimpoint pattern algorithm developed at the U.S. Army's Field Artillery School and Center, Ft. Sill, Oklahoma. It estimates the spread of the initial aimpoints of the rounds landing in the volley pattern using the Estimated Fendrikov Pattern Aiming Strategy. This strategy is used for both Blue and Red indirect firers.

(6) These changes have been called "minor modifications" in the VIC 4.0 documentation. The results of these differences seen in the validation runs made were small--reduction of kills on the targeted units less than 10 percent but increased over-all artillery kills due to the addition of collateral units' damage. Validation of the two artillery methodologies is a moot point since neither Eagle nor CAMEX have the latest Artillery Center- and AMSAA-approved artillery assessment algorithms.

b. *Validation.*

(1) Given that Eagle does not contain the updated Super Quickie 2 and SMART attrition algorithms found in CAMEX, validation runs of the two models to compare artillery results were stopped. The results of those runs completed did show very similar output (as noted before). Eagle artillery outputs are consistent with the expected results of VIC version 3.0 artillery algorithms (hand-cranked by calculator).

(2) Both Eagle and CAMEX need to be updated to the ARTQUIK and improved SMART set of artillery methodologies presently found in VIC versions 5.0 and 6.0. The implementation of these into Eagle will take at least one man-year with 18 to 24 man-months being a more realistic estimate of the effort needed.

5. Future work.

a. The data bases for at least one standard scenario that portrays exactly the same situation in both Eagle and VIC should be developed. All events should occur at exactly the same time and in the same manner. These data bases for the standard scenario would then be available for future validation efforts involving the two models. This development would also be an outstanding learning experience for analysts new to the "study side of the house."

b. Other topics for potential modeling changes in the direct-fire attrition functional area are:

(1) Within each of the combat models (Eagle, VIC, and CAMEX) that use the Bonder-Farrell methodologies, a probability of acquisition (p-acq) for the particular situation is calculated based solely on the input probability of ever-acquiring based on target contrast (the P-infinity mentioned above). This particular situation (p-acq) should be the probability of acquisition due to either gunflash or target contrast; but in all three models, the p-acq due to only target contrast is used. A new way to determine this situational p-acq using both the factor due to contrast and the factor due to gunflash could be developed and implemented.

(2) The use of phased engagement factors needs to be examined. This factor represents the fraction of the elements of an aggregated unit that are active participants in the direct-fire battle dependent on the range to the enemy. Phased engagement factors can be looked upon as solely a function of commander's intent (a gamer decision), solely a function of terrain (an environmental input based on the theater of operations), or a function of both commander's intent and terrain. Mr. Hannon, TRAC-OAC, and I have developed two similar approaches to change the use of the phased engagement

factors that consider these differing views. Presently, the phased engagement factors used are a function of terrain. Also phased engagement factors for SWA and Northeast Asia (NEA) scenarios need to be developed if it is decided that the theater of operations' terrain should affect those values.

(3) The search process when using the serial acquisition discipline within the Bonder-Farrell methodology is terminated with search cut-off time of the last target system within the target unit that is processed. Bonder and Farrell modeled the battlefield as a system of Markovian processes that had reached steady-state during an infinite time period. The search process is the first step taken in the "servicing" of the target. Killing the target is the second step in the service procedure, but the target may drive out of view or get killed by another firer before the particular shooter can complete service (kill) him. Instead of the infinite time available to search for new targets after the service operation for the previous target has been completed, the search cut-off time of the last target processed is used. In actual scenario gaming, this is usually not significant because the search cut-off time is large enough and the battlefield is "target rich" enough to accomplish most of the acquisitions that would have been possible in infinite time. However, if the last target system processed should have a small search cut-off time (< 30 seconds), the potential to under-represent the acquisition and thus the killing capabilities of the shooter exists and could affect the battle results. Code for both Eagle and VIC needs to be written that causes the target servicing procedure to "loop" an additional iteration for a search cut-off time of at least 999 seconds. After testing, this code should be implemented if it does not significantly lengthen run-time.

6. Conclusions.

a. The acquisition used for both direct-fire and helicopter on-station attrition, direct-fire attrition, helicopter on-station attrition, and indirect-fire attrition processes in Eagle have been verified. With the code changes made and exceptions noted in this report, Eagle's code does function as intended: 1987 VIC (version 3.0).

b. All the functional areas examined do validate to present VIC (versions 5 and 6) except indirect-fire attrition. Indirect-fire attrition does validate to the intended VIC version 3.0 algorithms. Eagle uses the Super Quickie 2 and SMART family of algorithms, but present VIC uses the Artillery Projectile Effectiveness model (ARTQUIK) and improved SMART set. Eagle should be updated to these latest AMSAA- and Field Artillery School-approved artillery methodologies.

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